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RESEARCH ARTICLE

Early prediction of maxillary canine impaction

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Objectives: The aim of this study was to establish prediction criteria for maxillary canine impaction in young patients, based on angular and linear measurements on panoramic radiographs.
Methods: From 828 records having at least 2 panoramic radiographs, both taken between the ages of 7 and 14 years, with a minimum 1-year and maximum 3-year interval (T1 and T2), a training data set consisting of 30 subjects with unilateral canine impaction (12 males and 18 females) was selected. The patients' mean age was 10.1 years [standard deviation (SD) 1.3 years] at T1 and 11.9 years (SD 1.1 years) at T2. The training data set also consisted of 30 maxillary canines from the contralateral sides and an additional 60 normal erupted canines from 30 subjects. Those 30 subjects of a test data set were selected based on displaying bilateral maxillary canine eruption at T2 and being matched for gender and age with the subjects of the training data set [12 males and 18 females; mean age at T1, 10.1 years (SD 1.3 years) and at T2, 11.1 years (SD 1.2 years)]. Angular and linear measurements were performed separately by two observers on the total study sample at T1. Linear measurements were expressed as a multiplication of the maxillary central incisor width at the non-impacted side.
Results: Significant differences for linear and angular measurements and radiographic factors were found between the maxillary impacted canine and erupted maxillary canine. The three best-discriminating parameters were canine to first premolar angle, canine cusp to midline distance and canine cusp to maxillary plane distance. These three parameters were combined in a multiple logistic regression model to calculate the probability of impaction, yielding a high area under the curve (AUC) equal to 0.97 (95% confidence interval: 0.94–0.99), with 90% sensitivity and 94% specificity.
Conclusions: Prediction of maxillary canine impaction from a combination of parameters relating to angles and distances measured in panoramic radiographs is weak. However, the final prediction model, based on canine–first premolar angle, canine cusp tip to midline distance and canine cusp tip to maxillary occlusal plane distance, might be useful to discriminate canine impaction for early intervention or regular follow-up.
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Introduction

Maxillary canines are the most frequently impacted teeth after the third molar,[1,2] with an incidence ranging from 0.9% to 2.2%.[1,3,4] Several authors reported that the palatal to buccal maxillary impaction ratio is 3 : 1,[5,6] with an incidence twice as high in females compared with males.[2,7]

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Several local, systemic and genetic factors for canine impaction have been proposed, but the exact aetiology remains unknown.[8] Two major theories may explain palatally displaced maxillary canines. The "genetic theory" refers to genetic factors as a primary cause and includes other possibly associated dental anomalies, such as missing or peg-shaped maxillary lateral incisors,[6,9] enamel hypoplasia of incisors and permanent first molars, aplasia of second premolars and infraocclusion of primary molars.[9] The "guidance theory" refers to lack of guidance by the adjacent teeth during canine eruption because of missing maxillary lateral incisors.[10]

Canine impaction has been reported to increase orthodontic treatment time, with complicated orthodontic treatment mechanics and increased treatment costs.[11,12] Therefore, the most desirable approach for managing impacted maxillary canines is early diagnosis and the interception of potential impaction.[13] The success of early interceptive treatment is influenced by the patient's age and the degree of impaction at diagnosis.[14] Ericson and Kurol[15] found that extracting the primary canines before the age of 11 years would normalize the eruption position of the permanent canines in 91% of the cases if the canine crown was distal to the axial line of the lateral incisor. When the crown was mesial to this reference line, the success rate decreased to 64%.[15,16]

In addition, vertical canine angulation exceeding 31° relative to the midline decreased success rates significantly, albeit to a lesser extent compared with canines overlapping with the lateral incisors.[17] After extraction of the primary canines, only 65% of the palatally displaced canines have been found to spontaneously erupt.[18] The success rate would improve to 88% by the addition of forces to prevent mesial migration of the maxillary posterior teeth after extraction, *i.e.* the use of cervical-pull headgear.[18,19]

The combination of extraction of the primary canines and rapid maxillary expansion in the late mixed dentition would lead to eruption of the canines in 80% of patients.[20] This shows that early interceptive treatment of maxillary canine impaction can often resolve the problem of early impaction and reduce subsequent treatment time, complexity and cost.[21] Thus, early diagnosis of maxillary canine impaction is crucial. Therefore, the aim of this study was to establish criteria based on angular and linear measurements from panoramic radiographs for the prediction of maxillary canine impaction in young patients.

Methods and materials

For this retrospective study, the patient database of the Department of Oral Health Research, University Hospitals Leuven, Leuven, Belgium, was screened for patient records that included at least two panoramic radiographs taken over the preceding 10 years, for various reasons of diagnosis and specific treatment needs. To be included in the present study, patient records were required to have at least two panoramic radiographs of good quality, both taken between the ages of 7 and 14 years, with minimum 1-year and maximum 3-year interval (T1 and T2). Records from patients with cleft lip and palate or other syndromes were excluded.

The primary database yielded a potential study population of 828 patients (386 males, 442 females). All radiographs were subsequently screened for maxillary canine impaction, defined, based on radiographic assessment, as an intraosseously located canine failing to erupt at its appropriate site in the dental arch while complete eruption of the contralateral side was observed at T2. In total, 712 of these patients were excluded. 271 patients showed spontaneously erupted canines on the first panoramic radiograph (T1). For 125 patients (56 males, 69 females), no maxillary canines erupted in both sides at the time of the second panoramic radiograph (T2), and 316 patients were excluded (167 males, 149 females) because of an intervention or treatment during the interval between T1 and T2 (*e.g.* extractions of the primary canines, early interceptive orthodontic treatment or orthodontic treatment). This resulted in a final sample of 116 untreated patients with unilateral canine impaction at T2.

From these 116 records, 30 subjects (training data set) showed unilateral canine impaction with a contralateral eruption of the maxillary canines at T2. Patients' mean age was 10.1 years [standard deviation (SD) 1.25 years] at T1 and 11.9 years (SD 1.10 years) at T2. In 12 patients (7 males and 5 females), the right maxillary canine was impacted, and in the remaining 18 patients (5 males and 13 females), the left maxillary canine was impacted.

The test data set consisted of 60 subjects with 90 normal erupted maxillary canines, 30 on the control side in training data set and an additional 60 from 30 subjects. Those 30 subjects were selected from the 86 remaining records that displayed bilateral maxillary canine eruption at T2 and were matched for gender and age with the patients of the test group [12 males and 18 females; mean age at T1, 10.10 years (SD 1.3 years) and at T2, 11.1 years (SD 1.2 years)].

Angular and linear measurements (Table 1) were performed separately by two observers for the total study sample at T1 (Figures 1–3). Linear measurements were expressed as a multiplication of the maxillary central incisor width at the non-impacted side. The maxillary central incisor width was arbitrarily set at 100. The distance between the cuspid or apex and the plane was measured perpendicular to the occlusal plane or midline.

Statistical methodology

Parameters for impacted and non-impacted teeth were compared by Mann–Whitney U tests. The significant difference does not imply that a parameter discriminates well between impacted and non-impacted canines. Therefore, based on the empirical distribution function of each parameter, the degree of discrimination between impaction and non-impaction was quantified with the area under the curve (AUC). This AUC ranges from 0.5 (random prediction) to 1 (perfect discrimination). For each parameter, the optimal cut-off point that optimizes the sum of

Table 1 Description of angular and linear measurements

Parameters	*Description*	*Symbol*
Angular measurements	Canine—first premolar angle	3^4
	Canine—lateral incisor angle	3^2
	Canine—central incisor angle	3^1
	Canine—occlusal maxillary plane angle[a]	3^OP1
	Canine—occlusal mandibular plane angle[b]	3^OP2
	Canine—midline angle[c]	3^ML
	Lateral incisor—occlusal maxillary plane angle[a]	2^OP1
	Lateral incisor—occlusal mandibular plane angle[b]	2^OP2
	Lateral incisor—first premolar angle	2^4
	Intercanine angle	3^3
Linear measurements	Canine cuspid to first premolar distance[d]	3c-PM
	Canine cuspid to lateral incisor distance[d]	3c-2
	Canine cuspid to central incisor distance[d]	3c-1
	Canine cuspid to maxillary plane distance[a,e]	3c-OP1
	Canine cuspid to mandibular plane distance[b,e]	3c-OP2
	Canine cuspid to midline distance[c,e]	3c-ML
	Canine apex to first premolar distance[d]	3a-PM
	Canine apex to lateral incisor distance[d]	3a-2
	Canine apex to central incisor distance[d]	3a-1
	Canine apex to occlusal maxillary plane distance[a,e]	3a-OP1
	Canine apex to occlusal mandibular plane distance[b,e]	3a-OP2
	Canine apex to midline distance[c,e]	3a-ML
	Lateral incisor to first premolar distance	2-4

[a]The occlusal maxillary plane was defined as a horizontal line tangent to the mesiobuccal cusp tip of the first permanent maxillary molar and the incisal edge of the first permanent maxillary incisor on the given side.
[b]The occlusal mandibular plane was defined as a horizontal line tangent to the mesiobuccal cusp tip of the first permanent maxillary molar and the incisal edge of the first permanent mandibular incisor on the given side.
[c]The midline was determined by the anterior nasal spine and the middle between the two central incisors.
[d]Tooth axis was used for the first premolars, canines, and lateral and central incisors.
[e]The distance between the cuspid or apex and the plane was measured perpendicular to the occlusal plane or midline.

sensitivity and specificity was determined. A multiple logistic regression model was used to combine the most discriminating parameters (avoiding a combination of highly correlated measurements). Given the sample size, no more than three parameters were included in this model. The AUC was reported on cross-validated predicted probabilities.

All analyses were performed using SAS® software v. 9.2 of the SAS System for Windows® (Copyright© 2002 SAS® Institute Inc., Cary, NC)

Results

In training data set subjects, significant differences for linear and angular measurement and radiographic factors were found between impaction and non-impaction sides (Table 2).

Comparison between radiographic factors in training data set subjects at T1 and T2 revealed that the position of the impacted canine relative to the midline remained the same, whereas the erupting

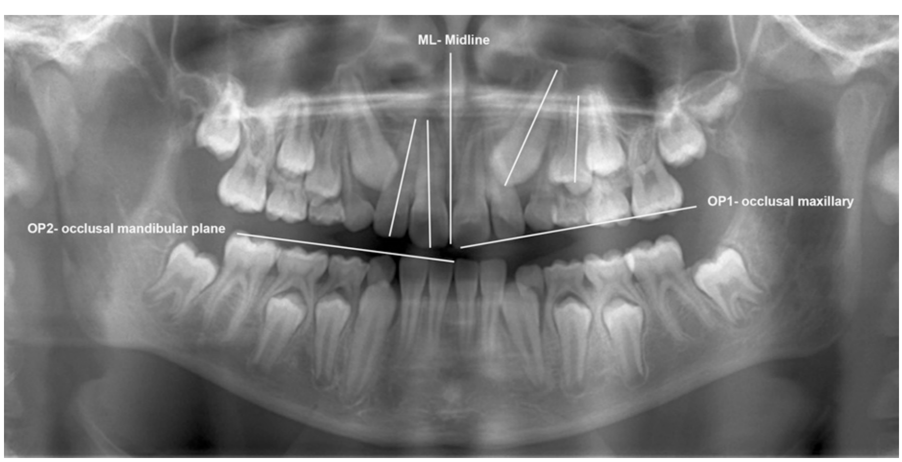

Figure 1 Panoramic image illustrating the reference lines of the midline (ML), occlusal maxillary plane (OP1), occlusal mandibular plane (OP2) and tooth axis for the first premolars, canines and lateral and central incisors.

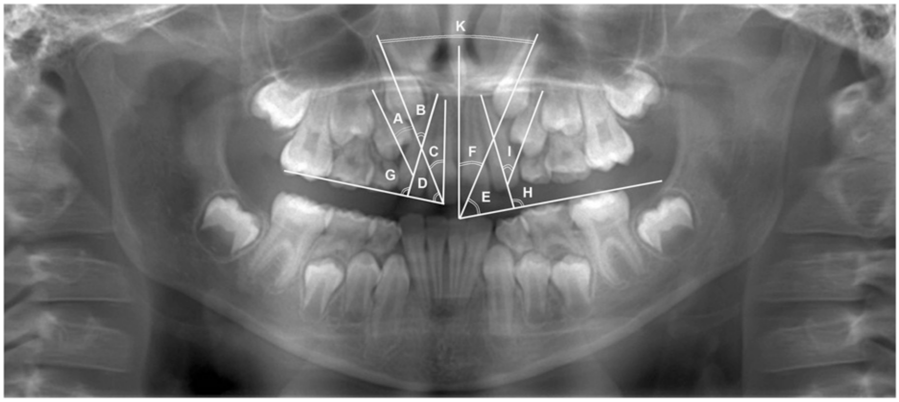

Figure 2 Panoramic image illustrating the angular measurements. (A) Canine angulation to the first premolar. (B) Canine angulation to the lateral incisor. (C) Canine angulation to the central incisor. (D) Canine angulation to the occlusal maxillary plane. (E) Canine angulation to the occlusal mandibular plane. (F) Canine angulation to the midline. (G) Lateral incisor angulation to the occlusal maxillary plane. (H) Lateral incisor angulation to the occlusal mandibular plane. (I) Lateral incisor angulation to the first premolar. (K) Intercanine angulation.

contralateral canine became significantly more upright (by 12° on average). The angle between the canine and the lateral incisor at T1 had nearly the same value but diminished at T2 on the impacted side (−13°) and increased on the non-impacted side (+5°). The angle between the premolar and the lateral incisor at T1 was identical for both study samples but diminished on the impacted side (−14°) and increased on the non-impacted side (+13°).

Table 3 shows the AUC to discriminate between impacted and non-impacted canines for each separate parameter. The optimal cut-off point was calculated, as were the resulting indices of sensitivity and specificity (Table 3).

The three best-discriminating parameters between impacted and non-impacted canines were canine to first premolar angle, canine cusp to midline distance and canine cusp to maxillary plane distance. These three parameters were combined in a multiple logistic regression model, yielding a high AUC equal to 0.97 (95% confidence interval: 0.94–0.99). With the receiver operating characteristic curve (Figure 4) giving equal weight to sensitivity and specificity, a canine would be classified as impacted when the predicted probability of impaction (PI) exceeds 0.42. The resulting sensitivity equals 90% and specificity equals 94%. The PI is obtained from the multiple logistic regression model, as follows:

$$\mathrm{PI}=\exp(\mu)/(1+\exp(\mu)),$$

where $\mu = -14.16 + 0.1675$ (canine to first premolar angle) $+ 0.0648$ (canine cusp to midline distance) $- 0.0423$ (canine cusp to maxillary plane distance).

Discussion

Panoramic radiographs are often taken in dentistry for different diagnostic reasons. The limitations of a panoramic radiograph, such as projection of a three-

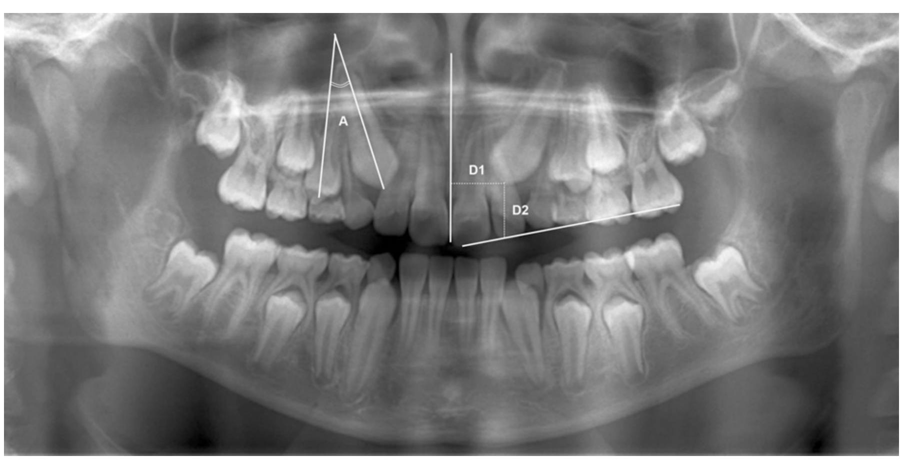

Figure 3 Panoramic image showing the three best-discriminating parameters between impacted and non-impacted canines. (A) Canine to first premolar angle. (D1) Canine cusp to midline distance and (D2) canine cusp to maxillary plane distance.

Table 2 Comparison between quantitative measurements at T1 Canine impaction *vs* non-impaction

Parameters	*Symbol*	*Canine impaction*		*Canine non-impaction*		*p-value*
		Mean (SD)	*Median (range)*	*Mean (SD)*	*Median (range)*	
Angular measurements	3^4	62.5 (17.0)	60.5 (41.7–121.8)	46.0 (11.9)	44.4 (11.0–79.3)	<0.01
	3^2	48.9 (25.0)	47.2 (13.5–143.2)	49.5 (24.9)	43.6 (10.4–151.9)	NS
	3^OP1	125.2 (13.8)	126.7 (90.8–154.0)	112.6 (19.4)	113.1 (63.3–148.5)	0.01
	3^OP2	123.8 (19.9)	126.0 (91.6–152.6)	119.2 (14.9)	120.9 (66.1–149.5)	NS
	3^ML	42.7 (12.6)	40.9 (18.3–63.9)	29.5 (19.9)	25.2 (0.9–79.0)	<0.01
	2^OP1	42.2 (13.3)	41.2 (17.6–93.4)	63.0 (25.3)	54.8 (20.8–124.0)	<0.01
	2^OP2	88.2 (21.8)	92.2 (38.1–140.0)	69.4 (22.8)	65.7 (31.4–166.0)	<0.01
	2^4	25.3 (13.2)	23.3 (6.4–64.7)	22.6 (11.7)	22.7 (1.1–53.7)	NS
Linear measurements	3c-4	127.4 (48.6)	121.8 (56.5–229.0)	116.9 (30.3)	116.5 (61.8–217.4)	NS
	3c-2	35.3 (31.1)	36.9 (−68.3–113.0)	57.8 (23.4)	59.3 (−40.0–110.6)	<0.01
	3c-1	102.0 (39.5)	111.2 (27.7–181.8)	136.3 (29.7)	136.8 (47.2–211.6)	<0.01
	3c-OP1	215.7 (48.2)	201.4 (133.5–380.9)	137.5 (51.2)	142.3 (8.0–304.4)	<0.01
	3c-OP2	285.9 (56.3)	277.0 (209.6–498.1)	198.2 (59.7)	197.5 (21.5–375.1)	<0.01
	3c-ML	153.4 (43.0)	162.3 (80.6–243.1)	218.4 (43.2)	214.2 (92.9–346.7)	<0.01
	3a-4	52.3 (37.2)	54.5 (3.3–161.1)	56.7 (29.2)	55.7 (1.3–151.1)	NS
	3a-2	174.3 (56.6)	176.5 (70.3–309.1)	159.5 (32.3)	159.6 (87.8–246.6)	NS
	3a-1	219.8 (58.8)	217.0 (105.5–364.7)	190.4 (30.1)	188.2 (96.1–274.8)	0.01
	3a-OP1	452.2 (72.9)	442.6 (243.1–611.4)	411.5 (52.6)	409.6 (252.0–556.0)	0.01
	3a-OP2	488.9 (95.8)	497.2 (79.6–611.4)	468.3 (74.5)	460.9 (82.6–723.2)	0.01
	3a-ML	274.7 (46.8)	269.0 (203.8–415.1)	222.6 (42.8)	226.2 (136.5–312.8)	<0.01
	2-4	68.2 (30.2)	78.6 (9.8–112.1)	83.4 (19.2)	85.5 (10.2–165.6)	0.03

NS, not significant; SD, standard deviation.
Refer to Table 1 for descriptions of symbols given in this table.

dimensional volume on a two-dimensional view, which inherently results in distortion, overlapping and loss of information, are well known.[22] This problem may be solved by the use of CBCT. However, much debate exists over radiation exposure. Therefore, it remains important to determine the criteria for the prediction of impaction based on panoramic radiographs. Furthermore, the reason for the use of panoramic radiographs is their availability in most dental records, especially for the youngest children, around the age of 10 years. Our methodology was to establish a screening protocol based on the standard available radiographs, to allow for early intervention in the possible indication of canine retention/impaction.

Three radiographic parameters were proposed to be indicative of maxillary canine impaction: canine cusp tip distance to the occlusal maxillary plane, angle between canine and midline and the amount of canine overlap with adjacent teeth (sectors).[15,23] Ericson and Kurol[15] showed that the mean distance between the canine cusp tip and the

Table 3 Strength of discrimination by area under the curve (AUC), optimal cut-off points to discriminate between impaction and non-impaction of the derived cut-point

Parameters	*Symbol*	*AUC (95% CI)*	*Cut-off point*	*Sensitivity*	*Specificity*
Angular measurements	3^4	0.83 (0.75–0.91)	48.2	27/30 (90.0%)	58/90 (64.4%)
	3^2	0.46 (0.33–0.59)	35.6	8/30 (26.7%)	76/90 (84.4%)
	3^OP1	0.68 (0.58–0.78)	122.7	21/30 (70.0%)	59/90 (65.6%)
	3^OP2	0.59 (0.44–0.73)	139.1	11/30 (36.7%)	86/90 (95.6%)
	3^ML	0.75 (0.66–0.84)	34.8	23/30 (76.7%)	65/90 (72.2%)
	2^OP1	0.79 (0.70–0.88)	48.0	26/30 (86.7%)	57/90 (63.3%)
	2^OP2	0.77 (0.67–0.87)	71.9	24/30 (80.0%)	65/90 (72.2%)
	2^4	0.53 (0.42–0.65)	14.0	26/30 (86.7%)	25/90 (27.8%)
Linear measurements	3c-4	0.53 (0.40–0.67)	159.7	8/30 (26.7%)	84/90 (93.3%)
	3c-2	0.76 (0.66–0.86)	44.3	19/30 (63.3%)	74/90 (82.2%)
	3c-1	0.77 (0.67–0.87)	135.3	25/30 (83.3%)	52/90 (57.8%)
	3c-OP1	0.90 (0.84–0.96)	184.6	24/30 (80.0%)	77/90 (85.6%)
	3c-OP2	0.89 (0.83–0.95)	240.1	26/30 (86.7%)	70/90 (77.8%)
	3c-ML	0.87 (0.80–0.94)	190.8	25/30 (83.3%)	68/90 (75.6%)
	3a-4	0.54 (0.42–0.67)	21.2	9/30 (30.0%)	79/90 (87.8%)
	3a-2	0.59 (0.45–0.73)	188.2	14/30 (46.7%)	75/90 (83.3%)
	3a-1	0.70 (0.57–0.82)	216.5	15/30 (50.0%)	77/90 (85.6%)
	3a-OP1	0.69 (0.58–0.81)	434.9	18/30 (60.0%)	65/90 (72.2%)
	3a-OP2	0.64 (0.53–0.76)	469.5	21/30 (70.0%)	53/90 (58.9%)
	3a-ML	0.80 (0.72–0.88)	249.8	23/30 (76.7%)	68/90 (75.6%)
	2-4	0.63 (0.50–0.76)	74.1	14/30 (46.7%)	72/90 (80.0%)

CI, confidence interval.
Refer to Table 1 for descriptions of symbols given in this table.

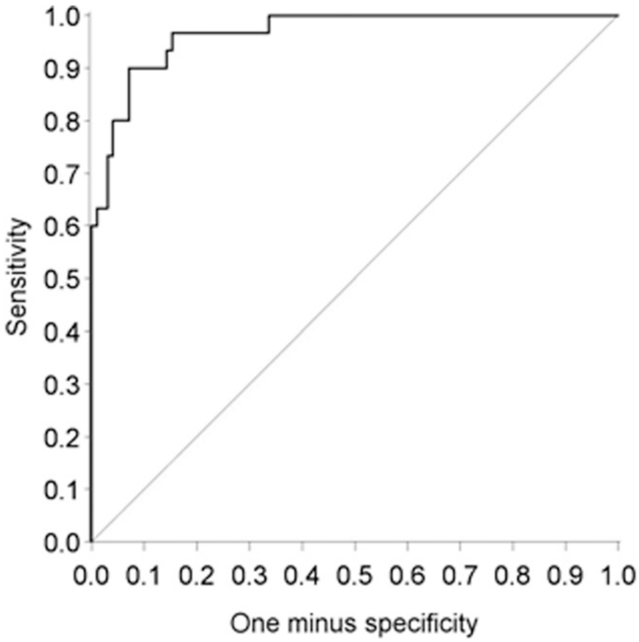

Figure 4 Receiver operating characteristic curve: discrimination between impaction and non-impaction. Discrimination is based upon the multiple regression model with the three best-discriminating measurements (3^4, 3c-ML and 3c-OP1). Area under the curve = 0.97 (95% confidence interval: 0.94–0.99). The optimal cut-off point of probability is equal to 0.42, yielding a sensitivity of 90% and a specificity of 94%.

occlusal maxillary plane is larger in cases of an impacted canine. The clinically discernible difference was found equal of 4 mm for the distance between canine cusp tip and the occlusal maxillary plane between impacted and non-impacted canines in 8-year-old children.[24] In a separate study, in children older than 9 years, a statistically significant difference found for the distance from the canine cusp tip to the occlusal maxillary plane was the most important predictor of impaction, more than all other measurements performed on panoramic radiographs between impacted and non-impacted canines.[25]

Statistically significant differences between impacted and non-impacted canines can be found. However, more important than significant differences is the clinician's ability to discriminate clinically between impacted and non-impacted canines. This degree of discrimination is quantified by an index, which, in this setting, coincides with the area under the receiver operating characteristic curve or AUC. Therefore, the present study aimed to discriminate clinically between impacted and non-impacted canines based on predictive criteria involving angular and linear measurements on panoramic radiographs. Linear and angular measurements were included in this study to predict canine impaction, because they are frequently used as comparative parameters for impacted canine assessment.[15,17,26]

Treatment methodology for impacted canines depends on various factors such as location of the impacted canine in the dental arch relative to adjacent incisors, the distance from the occlusal plane, canine crown overlaps and canine angulations.[27,28] Several authors[29,30] have suggested that linear measurements in panoramic radiographs are reliable. However, by contrast, some authors[31–33] decided not to use linear measurements on panoramic radiographs owing to the amount of distortion and magnification. In this study, the magnification factor was taken into account in linear measurements. Therefore, all linear measurements were related to the width of the central incisor and expressed as a ratio. Furthermore, panoramic radiographs were taken by well-trained radiological technicians who perform these examinations daily and are supervised by a recognized and certified oral radiologist.

The present study population was selected from a clinical database, according to clearly defined inclusion and exclusion criteria. 60% of the subjects were female. Several authors[2,7,34] have reported that the prevalence of impaction is greater in females than in males, but a high variation in the distribution of unilaterally impacted canines appears to exist.[24] Other authors reported either a higher incidence on the right side[35] or a balanced distribution.[34,36]

Comparison of the positions of the canines over a specific time interval illustrates a difference between impacted and non-impacted canines. The angle between the canine and the lateral incisor was reduced on the impacted side and increased on the non-impacted side. This was found for the angle between the premolar and the lateral incisor. Simultaneously, the angle between the canine and the midline was stable in the impacted canine but increased during eruption of the canine in the non-impacted canine sample. The canine overlap with the adjacent teeth (sector) was found to be a predictor of early canine displacement.[37–39] The difference in overlap has been found to be depending on the development of the lateral incisors when they were not yet fully developed. In the present study, a significant difference was found between impacted and non-impacted canines for the distance from the canine cusp tip to the midline angle, which is in agreement with results of previous studies. The canine angle to the first premolar was shown to be a good discriminator, with a cut-off point of 48.2° (Table 3). The more the angle exceeds the cut-off point, the higher the probability for impaction.

A priori comparison of the non-impacted canines of individuals with unilateral impaction with non-impacted canines from control individuals could be inappropriate. However, in the statistical analysis, the dependency of canine impaction was ignored. The small numbers in the study sample were because of the fact that few patients were found without early treatment or with extractions between T1 and T2. Conversely, the prevalence of untreated impacted canines was inherently relatively small because of the prominent functional and aesthetic position of the canine in the dental arch.

To improve the discriminative ability, the best-performing parameters were combined in a multiple logistic regression model. The number of parameters was restricted to three because of the relatively small number of impacted canines (n = 30) as well as to avoid the risk of overfitting. The distance from the canine cusp tip to the mandibular plane was not considered owing to the high correlation with the distance from the canine cusp tip to the maxillary plane. Therefore, combining the first premolar angle to the canine, the distance from the canine cusp tip to the midline and the distance from the canine cusp tip to the maxillary plane gives a high AUC of 0.97 for the study sample, with a sensitivity of 90% and a specificity of 94%. Therefore, the prediction of canine impaction based on panoramic radiographs seems to be weak. Further validation of non-treated canine impaction on a larger scale is needed to draw conclusions for future predictions.

Conclusions

The three best-discriminating parameters between impacted and non-impacted canines were canine to first premolar angle, canine cusp to midline distance and canine cusp to maxillary plane distance. Prediction of maxillary canine impaction based on panoramic radiographs based on a combination of parameters such as angles and distances is weak. However, the final prediction model, based on canine-first premolar angle, canine cusp tip to midline distance and canine cusp tip to maxillary occlusal plane distance, might be useful to discriminate canine impaction for early intervention or regular follow-up.

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